Bike-sharing Systems' Impact on Modal Shift: A Case Study in Delft, the Netherlands

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Abstract

Bike-sharing has been found to influence modal shift from car, public transit, and active transportation modes. This study examines the modal shift dynamics and the influential factors on modal shift in response to various bike-sharing systems. Data are obtained by an online survey targeting both non-bike-sharing users and bike-sharing users in a Dutch context. Binary logit models are developed to investigate the relationship between modal shift to bike-sharing with socio-demographic, commuting trip and motivation factors. The survey results show that dockless bike-sharing (Mobike) users are more likely to be non-domestics and often have no driving license, whereas the situation is opposite for docked bike-sharing (OV-fiets), bicycle-lease (Swapfiets) and non-bike-sharing users. Except for train use, bike-sharing users reduced walking, the use of private bicycle, bus/tram and car. Swapfiets showed a most significant influence on modal shift for both single and multimodal trips. The regression model results indicate that "No stolen/damage problem" and "Cheaper than other modes" are significant factors promoting dockless bike-sharing and bicycle-lease. "Good quality of bicycles" is a significant factor considered by docked bike-sharing and bicycle-lease users. "Public transport subsidy by employer" encourages commuters to shift to docked bike-sharing, whereas "Student discount" discourages the shift to bicycle-lease. Male and multimodal commuters are more likely to use dockless bike-sharing. Commuters are less likely to shift to docked bike-sharing if the trips are "Short" or suitable for "Private bicycle". The findings provide a clear understanding of the modal shift and its determinants that can serve as an empirical basis for development of more effective targeted measures to encourage modal shift in areas with coexistence of various bike-sharing schemes.

Keywords: Dockless bike-sharing, docked bike-sharing, bicycle-lease, modal shift, commuting, binary logit model

1 Introduction

The rapidly increasing rate of global urbanization and the number of private vehicles have caused great social and environmental problems such as noise, traffic congestion, and air pollution (Morton, 2018; Nikitas, 2018). In response to this, bike-sharing programs are now widely accepted as a new non-motorized transport mode to mitigate these problems (Chen et al., 2018). Bike-sharing systems are often used for short-distance trips and have been widely deployed in numerous cities worldwide (Dilay et al., 2018; Liu et al., 2019; Zhang et al., 2015). Previous studies have summarized that bike-sharing is flexible, economical, and good for health; it helps cut down emissions, ease congestion, reduce fuel usage; and supports multimodal transport connections (Fishman et al., 2014; Shaheen et al., 2010).

The first-generation of bike-sharing, known as "White Bikes" (or Free Bike Systems), emerged in 1965 in Amsterdam (Shaheen et al., 2011). These bicycles were unlocked and free for public use. This program survived for only a short time, ultimately succumbing to a series of problems such as theft and vandalism (Shaheen et al., 2010). The second-generation of bike-sharing was initially opened in Denmark in 1991 (Demaio, 2009). It was also known as "Coin Deposit Systems" and required a refundable deposit to unlock and use a bicycle. Users often kept bicycles for extended time periods because this system did not limit bicycle usage time. To deter theft and encourage bicycle return, the third-generation bike-sharing system was opened in France in 1998 (Shaheen et al., 2011). A number of new characteristics (improved bicycle designs, sophisticated docking stations and automated smartcards (or magnetic stripe cards) electronic bicycle locking and payment systems) differentiate third-generation systems from the previous generations (Shaheen et al., 2010). In the last years, some scholars concluded that the fourth-generation systems are characterized by the highly flexible dockless system with the use of GPS and smart phones, easier installation, and power assistance (Fishman and Cherry, 2016; Gu et al., 2019; Parkes et al., 2013). Currently, bike-sharing systems operated worldwide can be divided into two categories: docked bike sharing and dockless bike sharing (Liu et al., 2018). In the docked bike-sharing system, users have to rent bicycles from designated docking stations and then return them to the available lockers in docking stations. The dockless bike-sharing system is designed to provide more freedom and flexibility to travellers in terms of bicycle accessibility. In contrast to docked bike-sharing, riders are free to leave bicycles in either physical or geo-fencing designated parking areas provided in public space with or without bicycle racks.

Bike-sharing systems have resulted in modal shift impact on car, public transit, and active transportation modes like walking and bicycling (Daniel et al., 2013; Hsu et al., 2018; Martin and Shaheen, 2014). The modal shift towards bike-sharing might improve the quality of the urban environment (Cerutti et al., 2019), reduce traffic noise (Beckx et al., 2013), alleviate congestion (Shaheen et al., 2013) and enhance physical well-being (Lee et al., 2017). Previous literature has focused on the modal shift caused by either docked or dockless bike-sharing system. However, the impacts on modal shift by considering different kinds of bike-sharing systems are rarely discussed. A deep understanding of modal shift in response to bike-sharing can offer meaningful implications for policy makers and bike-sharing companies to improve their service. This paper investigates the travel modal shift dynamics and the factors influencing users' choices in response to different bikeshare systems in a Dutch city with mature cycling culture - Delft, the Netherlands.

This paper aims to understand the modal shift dynamics and the determinants on travelers' choices in response to different bike-sharing systems by conducting a survey targeting OV-fiets users, Mobike users, Swapfiets users and non-bike-sharing users.

The specific research questions are given as follows:

1) What are the user characteristics in the different bike-sharing systems? What are the motivations for the travelers to use bike-sharing?

2) What are the impacts of different bike-share systems on modal shift?

3) How can personal attributes, commuting trip characteristics and motivations towards bike-sharing system affect people's modal shift in commuting trips in response to different bikeshare systems?

In the following sections, we proceed with a literature review on modal shift caused by bike-sharing systems. Next, a brief overview on the study area and the existing bike-sharing systems is provided. Then, we describe the data collection, the data and the methods applied in this analysis, followed by the results and conclusions.

2 Literature review

Modal shift is defined as the shift from other modes of transport such as walking, cycling, public transport and car to bike-sharing in a single trip or multiple trips. Previous modal shift studies in relation to bike-sharing can be divided into three groups: (a) active mode modal shift dynamics in response to bike-sharing; (b) public transit modal shift dynamics in response to bike-sharing (c) car modal shift in response to bike-sharing.

(1) Active mode modal shift dynamics in response to bike-sharing

Daniel et al. (2013) pointed out that active travel levels increased along with bike-sharing usage (4.71% for cycling and 2.92% for walking). Fishman et al. (2015) used a Markov Chain Monte Carlo analysis to estimate the bike-sharing' impact on active mode travel in the United States, Great Britain, and Australia. Results showed that bike-sharing's impact on active travel was dependent on the mode bikeshare replaced. When bike-sharing replaced a walking trip, there was a reduction in active travel time. Considering the active travel balance sheet, bike-sharing had an overall positive impact on active travel time. Campbell et al. (2016) used a stated preference survey to explore the factors influencing the choice of bike-sharing and electric bike-sharing. They found that both bikeshare systems would tend to draw users away from walking, private bicycles and e-bikes. Fan et al. (2019) collected travelers' mode choice for first/last mile trips before and after the introduction of bike-sharing system and found that most shifted trips towards bike-sharing were original walking or private bicycle trips. By comparing the trip chains before and after the introduction of bike-sharing, Zhu et al. (2012) observed that 47.3% of shifted trips resulted from walking. Most people shifted to bike-sharing from walking stated it was tiring to walk all the way and bike-sharing could also decreased the travel time (Yang et al., 2016). Private bicycle users before the introduction of bike-sharing systems reported that it was inconvenient to carry their own bicycles on the train and that the flexibility and accessibility of bike-sharing were the main reasons that attracted them. In addition, some bicyclers shifted to bike-sharing to avoid bicycle theft (Daniel et al., 2013; Fan et al., 2019).

(2) Public transit modal shift dynamics in response to bike-sharing

Previous research has shown that bike-sharing has a potential to increase public transit trips and that the integration of bike-sharing and public transit has been shown to strengthen the benefits of both modes (Brand et al., 2017; Joeri et al., 2018; Kager et al., 2016; Nair et al., 2013; Oort et al., 2019; Shelat et al., 2018; Yang et al., 2016). Using multi-source data (e.g., survey data, zip code-level population statistics), Shaheen et al. (2014) and Martin and Shaheen (2014) evaluated public transit modal shift patterns in response to bike-sharing. They found that bike-sharing tended to be more substitutive to public transport in larger and denser cities and more complementary as a first/last mile integration in small to medium size and less denser cities. Shaheen et al. (2013) also found that increased age, being male, living in lower density areas, and longer commute distances were common attributes associated with shifting from public transit to bike-sharing. Recently, a linear regression model was developed to estimate the impact of bike-sharing use on bus ridership. Results showed that the bike-sharing had some negative effect on bus ridership (Prasad et al., 2019). Yang et al. (2016) conducted a pre and post survey survey and analyzed users' perceptions of passengers who shifted to bike-sharing. They concluded that the long waiting time, crowded space in bus and the wasted time in traffic jams were the main reasons why they shifted from bus to bike-sharing.

(3) Car modal shift in response to bike-sharing

Although bike-sharing is not explicitly designed to shift passengers directly from car usage to active transportation mode (Daniel et al., 2013), it has universally reduced personal driving and taxi use (Shaheen et al., 2012), especially for short trips in central downtown areas (Braun et al., 2016; Lin and Yang, 2011; Park and Sohn, 2017). Both Fan et al. (2019) and Shaheen et al. (2013) revealed that the reduction of car use was partly driven by trips in which bike-sharing provided a first/ last mile integration with public transit. Interestingly, Yang et al. (2016) concluded that the percent of car ownership of metro-bikesharing users (48.8%) was more than twice compared with the percent of car owners in the district (19.7%). Previous studies have shown that only a minority of car trips were replaced by bike-sharing journeys. For instance, Daniel et al. (2013) conducted two cross sectional telephone surveys and proposed a calculation method to estimate the modal shift in responds to bike-sharing system. They observed that the percent of modal shift from car to bike-sharing was approximately 0.3%-0.4%. Tang et al. (2011) investigated the modal shift in response to bike-sharing programs in Chinese cities. They found that only 5.2%, 4% and 0.46% of total car trips were replaced by bike-sharing trips in Beijing, Shanghai, and Hangzhou, respectively. According to the statistical results of Montreal, Toronto, Washington, D.C., Minneapolis-Saint Paul and London, the percentages of modal shift from car to bike-sharing were 3.6%, 2.0%, 2.1%, 1.9%, 2%, respectively(Fishman et al., 2014; Shaheen and Martin, 2015). However, the car substitution by bike-sharing in Minnesota, Melbourne and Brisbane were relatively high, namely 19%, 21% and 19% respectively(Fishman et al., 2014). In the survey conducted by Yang et al. (2016), the long drive, the inconvenience of finding a parking space, transportation congestion, and the high commuting expense were regarded as the top reasons for shifting from private car to bike-sharing, as well as the high travel cost for taxi users (Fuller et al., 2013; Zhou and Ni., 2018).

Previous literature has mainly focused on either docked or dockless bike-sharing systems. None has compared the impacts on modal shift by considering different kinds of bike-sharing systems in a same study. This represents a significant knowledge gap: we do not know how different bike-sharing users change their (main) modes; neither we know whether socioeconomic, commuting trip and motivation variables have differential impacts on people's modal shift behavior in response to different bikeshare systems.

This study examines modal shift patterns and the effects of personal, commuting trip characteristics and motivation factors on modal shift in a Dutch city where cycling is a prevailing transport mode. Data were obtained from a survey of 565 respondents conducted in June 2019 (including OV-fiets users, Mobike users, Swapfiets users and non-bike-sharing users) in Delft, the Netherlands. Binary logit models are established to quantify the effects of various variables on modal shift to bike-sharing.

3. Bike-sharing systems in Delft: A Brief Overview

As a university town, Delft is located in the western part of the Netherlands. It is a medium-sized city with approximately 100,000 inhabitants situated between the second and third largest cities of the Netherlands, Rotterdam and The Hague. The general mode share of the inhabitants of Delft is as follows: car 40%, bicycle 27%, public transport 6% and walking 25% (Heinen and Handy, 2012). With a long-standing bicycle culture, positive attitudes towards cycling and good cycling facilities, Dutch cities possess the highest rate of bicycle use in the world (Heinen et al., 2013). In Delft there exists three bikeshare systems in operations, including OV-fiets (Docked bike-sharing system), Mobike (Dockless bike-sharing system) and Swapfiets (Bicycle-lease system).

As shown is Table 1, OV-fiets, categorized as a docked bike-sharing system, was launched in the

Netherlands in 2003 and now they are operated by the Dutch railway corporation (NS) to promote first/last mile trips (van Waes et al., 2018). Unlike the docked bike-sharing systems whose related docking stations are allocated throughout an urban region, OV-fiets stations are mostly located near railway stations and bus/metro stops. The bicycles should always be brought back to the location where the rental started. It is also possible to return the bicycle at another station for an additional fee of €10. The bicycle can be rent by using personal public transport chip card, costing € 3.85 per 24 hours.

Mobike was launched in the Netherlands in 2017(Boor, 2019). No docking stations are needed in this bike-sharing system, bicycles can be parked in the operational areas defined by the Mobike company. With embeded GPS tracking module, Mobike allows riders to find and rent bicycles by using their smartphone APPs (Zhang et al., 2019). Users can use Mobike on a Membership Basis of €12/month or €49.9/year, or a Casual Basis of €1.5/20min. Note that near train stations Mobike has to be parked on a temporary parking facility that is generally around 150m away from the train stations to avoid the competition with OV-fiets.

Swapfiets was launched in the Netherlands in 2014, which is a bicycle-lease system on a subscription basis (thus can be considered a generalized bike-sharing system). After registration online or on a Swapfiets APP, users can get their personal Swapfiets bicycle within 1 day at a location of their choice. Users can rent the Swapfiets bicycles for € 15/month and the Swapfies team will repair the bicycles without extra costs. The coexistence of different bike-sharing schemes in Delft enables this city to be a test bed for bike-sharing research.

TABLE 1. Bike-sharing Systems in Delft, Netherlands

Bike-sharing Type	OV-fiets	Mobike	Swapfiets
Image illustration			
Year Launched in the Netherlands	2003	2017	2014
Feature of systems	Docked bike-sharing system	Dockless bike-sharing system	Bicycle-lease system on a subscription basis
Way to use	1.Subscription online or on a NS App 2. Using the Personal public transport chip card (NS card) to rent a bike.	1.Subscription on a Mobike App 2.Using the Mobike App to open the bike.	Subscription online or on a Swapfiets App and get a Swapfiets bike within 1 day at a location of your choice
User pricing	€ 3.85/day	€ 12/month, 49.90/year or €1.5/20min	€ 15/month

4. Methodology

This study examines the modal shift patterns and the explanatory factors that can influence modal shift in response to various bike-sharing systems. This section presents the survey design, data collection and regression model.

4.1 Survey design

The survey targets on both non-bikesharing users and bike-sharing (Mobike, OV-fiets, Swapfiets) users. Respondents were asked about their personal characteristics, including occupation, age group, gender, monthly (gross) income level, education background level, ethnic/culture background, vehicle ownership, transport subsidy situation, ownership of driving license (see Table 2). For the bike-sharing users, three additional parts were asked: the modal shift questions, commuting trip information and the motivations of using bike-sharing. Specifically, the modal shift questions were asked to evaluate the change in the travel modes including walking, private bicycle, Swapfiets, OV-fiets, private E-bike, bus/tram/metro, train, private car (driver/passenger), taxi and carsharing. The respondent could select one response from: "much more often" "more often" "about the same", "less often", "much less often" and "I never used this mode before". In addition, as commuting purpose is found as the main purpose of using bike-sharing (Cai et al., 2019; Martin and Shaheen, 2014), the changes of respondents' travel modes for commuting purpose after the introduction of bike-sharing were also included in this survey. Next, commuting trip information were asked, including commuting time, commuting distance and travel modes used for commuting. The final part was about the perceived motivations of using bike-sharing (see Table 2).

4.2 Data collection

The survey design was implemented in the Collector platform for web dissemination. This survey commenced on 10th June 2019, and ended on 5th July 2019. Several survey distribution ways were adopted for collecting responses. For instance, weblinks to the surveys were emailed to university electronic mailing lists; posts with weblinks were uploaded in different social media platforms including Facebook, LinkedIn, and Twitter; flyers with weblinks were distrusted by a face-to-face interview. Twenty interviewers were deployed for the face-to-face interview mainly during morning and evening peak hours, at the train stations, the campus, city center and different student housing facilities because of the large amount of bicycle trips. The average time taken for the survey is about 20 minutes.

4.3 Model Specification

In order to investigate commuters' modal shift toward bike-sharing systems, binary logit model, which is an often used and analytically convenient modeling method for discovering the correlations between modal shift and explanatory variables (Li and Kamargianni 2019; Soltani et al., 2019). The dependent variable is whether or not the respondent shifted their commuting mode to bike-sharing. Mathematically, let MS (modal shift) and NMS (no modal shift) be the two alternatives in the binary choice set of each individual (Ben-Akiva and Bierlaire, 1999):

$$\mathrm{U}_{in} = \mathrm{V}_{in} + \varepsilon_{in} \tag{1}$$

$$\mathrm{V}_{in} = \sum_{i=1}^{k} \beta_\mathrm{i} \mathrm{x}_\mathrm{i} \tag{2}$$

where:

U_{in}—the utility of the alternative *i* (either MS or NMS) to the n^{th} individual;

V_{in} —the deterministic or observable portion of the utility estimated to the n^{th} individual;

ε_{in}—the error of the portion of the utility unknown to the n^{th} individual;

x_i — a vector of independents variables, including factors of socio-demographic characteristics, commuting trip characteristics and motivations;

β_i — a vector of estimated coefficients.

When ε is independent and identically (i.i.d.) Gumbel distributed, the probability that the n^{th} individual will choose modal shift can be written as (Ben-Akiva and Bierlaire, 1999):

$$\mathrm{P}_{MSn} = \frac{1}{1+e^{-\mathrm{V}_n}} = \frac{e^{V_{MSn}}}{e^{V_{MSn}}+e^{V_{NMSn}}} \tag{3}$$

Table 2 summarizes the considering model variables. Note that we consider three independent binary logit models for each of the bike-sharing systems.

TABLE 2 Description of Variables in the Binary Logit Models

Variable name	Description
Dependent variables	Shift to Mobike=1, No shift=0; Shift to OV-fiets=1, No shift=0; Shift to Swapfiets=1, No shift=0
Independent variables	
Socioeconomic variables	
Nation	Dutch=0, Non-Dutch=1
Gender	Female=0, Male=1
Age group	Below 34=1, 35-54 =2, Over 55 =3
Monthly (gross) income level	Less than 2000€=1, 2000–3000€ =2, 3000–4000€ =3, More than 4000€
Education level	Low =1, Medium =2, High =3
Private car/ Private bicycle/E-bicycle ownership	No=0，Yes=1
Private car subsidy	No=0，Yes=1
Public transport subsidy	No=0，Yes=1
NS tickets discount (private)	No=0，Yes=1
Student discount (for Dutch) (Student-travel-product)	No=0，Yes=1
Driving licence ownership	No=0，Yes=1
Commuting trip variables	
Commuting distance	Self-reported distance, in kilometer
Commuting time	Self-reported time, in minutes
Commuting travel modes	Single mode=0, Multiple modes=1
Motivation variables	
Cheaper than other modes	Cheaper than other travel modes=1; Otherwise=0
Cheaper than owning a bicycle	Cheaper than owning a private bicycle=1; Otherwise=0
Less effort	Less effort than walking=1; Otherwise=0
No stolen/damaged problem	Less worried about being stolen/damaged=1; Otherwise=0
Comfortable	More comfortable than other travel modes=1; Otherwise=0
Convenient	More convenient than other travel modes=1; Otherwise=0
No parking	No vehicle parking problem=1; Otherwise=0
Saving time	Saving time than other travel modes=1; Otherwise=0
Exercise/fitness	Good for Exercise/fitness=1; Otherwise=0
Environment	Beneficial to the environment=1; Otherwise=0
Trendy travel model	Trendy travel mode=1; Otherwise=0
Short distance	Short trip distance than other choices=1; Otherwise=0
Good quality of bicycles	Good quality of bicycles=1; Otherwise=0
Mobile phone to lock the bike	Using mobile phone app to lock the bike=1; Otherwise=0
NS card to lock the bike	Using NS card to lock the bike=1; Otherwise=0
Dockless service	Dockless service, no fixed pick-up and drop-off locations=1; Otherwise=0

5 Result and discussion

The results are presented in five components. Firstly, the socio-demographic characteristics of the survey samples are described. The second part reports the perceptions of the motivations for using bike-sharing, followed by the modal shift dynamics caused by bike-sharing systems in the third and the fourth parts. Finally, the model results reveal the factors affecting people's modal shift in commuting.

5.1. Socio-demographic profile

A total of 622 respondents completed the surveys. After removing the data with incomplete information, a total sample size of 565 is obtained. The statistics of sample composition is presented in Table 3.

As shown in Table 3, for Mobike bike-sharing, Dutch users are fewer than Non-Dutch users (60.20% and 39.80% respectively). This is reasonable that Delft is a university town (Heinen et al., 2011) and international students might prefer to use Mobike instead of buying a private bicycle because of the lower rental cost. As for the rest of the three kinds of respondents, Dutch users are more than Non-Dutch users, particularly there is a large difference for OVfiets users (77.50% and 22.50% respectively). This is because the Dutch are more likely to be attracted by the fact that OV-fiets is connected to railway systems and it has a high level of public acceptance. The age distribution of the samples in each user group is consistent with each other, concentrating on the group aged from 18 to 24, followed by the group aged from 25 to 34. The group aged over 55 takes up only a small proportion, which may be because of the limited access to computers and/or smart phones which are required for online survey. The proportion of male group is higher than that of female, which is aligned with the study conducted by Stam (2019). Besides, the gender disparity is the smallest for OV-fiets group. The income distribution also shows consistency amongst different user groups. The user proportion decreases when income increases. All the four kinds of respondents are mainly with an income lower than or equal to 2000€/month. Over 85% of all the respondents are with a bachelor degree, which coincides with the survey results of Heinen and Handy (2012), which reported that people in Delft have a relatively higher education level compared to the national average. As for vehicle ownership, OV-fiets group has the highest proportion of private bicycle(s) (97.90%), followed by non-bike-sharing user group (94.80%), Mobike group (79.59%) and Swapfiets group (77.90%). Although the Netherlands is one of the countries which are leading e-bike markets in Europe, accounting for 21% of all EU sales (Fishman and Christopher, 2016), the e-bike ownership of sample size is very low, with the highest ratio being 5.70% for regular bike users. Besides, non-bike-sharing users have the highest proportion of car ownership (26.30%), followed by OV-fiets users (21.80%). Swapfiets users and Mobike users take up a small proportion of 8.40% and 8.16%, respectively. The low proportion of car ownership is because more 60% of respondents is students. 41.20% of non-bike-sharing users do not have any transportation allowance, whereas 74.60% of OV-fiets users have transportation allowance. This is because that OV-fiets subscription is usually coupled with public-transport cards which are purchased by either employer or travelers themselves. In particular, OV-fiets users have the highest ratio in terms of public transport subsidy and NS tickets with discount (27.50% and 23.20% respectively). Swapfiets users take up the highest proportion of 43.50% in terms of student discount from government because 85.50% of Swapfiets users are sutdents. Among Mobike users, the proportion of driving license owners is lower than those without it (51.02%>47.69%), while the situation with the other three groups is quite the opposite. This is reasonable because 60.20% of Mobike users are non-Dutch and 70.41% of them are students. The international students may not necessary to get a driving license. Of the four kinds of respondents, the majority are students and employees. Students, in particular, take up the highest proportion, contributing to 85.50% for Swapfiets and 70.41% for Mobike. As for employees, OV-fiets and non-bike-sharing users have higher rates of 40.10% and 33.00% respectively.

TABLE 3 Sample Composition

Variable	Category	Non-Bike-sharing N=194 [(%)]	Bike-sharing Mobike N=98 [(%)]	OV-fiets N=142 [(%)]	Swapfiets N=131 [(%)]
Ethnic/culture background	Dutch	106 (54.60)	39(39.80)	110 (77.50)	72 (55)
	Non-Dutch	88 (45.40)	59(60.20)	32 (22.50)	59 (45)
Age	⩽17	2 (1)	0 (0)	0 (0)	1 (0.80)
	18-24	85 (43.80)	46(46.94)	65 (45.80)	86 (65.60)
	25-34	73 (37.60)	41(41.84)	57 (40.10)	42 (32.10)
	35-44	16 (8.20)	10(10.20)	7 (4.90)	2 (1.50)
	45-54	9 (4.60)	1(1.02)	9 (6.30)	0 (0)
	55-64	6 (3.10)	0(0)	4 (2.80)	0 (0)
	65 +	3 (1.50)	0(0)	0 (0)	0 (0)
Gender	Male	124 (63.90)	68 (69.39)	77 (54.20)	91 (69.50)
	Female	68 (35.10)	30 (30.61)	63 (44.40)	40 (30.50)
	Other	2 (1)	0(0)	2 (1.40)	0 (0)
Monthly (gross) income	⩽2000€	124 (63.90)	72 (73.47)	81 (57)	106 (80.90)
	2000–3000€	25 (12.90)	9 (9.18)	28 (19.70)	18 (13.70)
	3000–4000€	15 (7.70)	8 (8.16)	14 (9.90)	0 (0)
	4000€ +	14 (7.20)	6 (6.12)	10 (7)	1 (0.80)
	Prefer not to say	16 (8.20)	3 (3.06)	9 (6.30)	6 (4.60)
Education	Low	0 (0)	0 (0)	0 (0)	3 (2.30)
	Medium	10 (5.20)	4 (4.08)	9 (6.30)	14 (10.70)
	High	180 (92.80)	91 (92.86)	133 (93.70)	112 (85.50)
	Others	4 (2)	3 (3.06)	0 (0)	2 (1.50)
Vehicle ownership (Multiple choice)	Private bicycle(s)	184 (94.80)	78 (79.59)	139 (97.90)	102 (77.90)
	Private E-bike(s)	11 (5.70)	3 (3.06)	5 (3.50)	1 (0.80)
	Car(s)	51 (26.30)	8 (8.16)	31 (21.80)	11 (8.40)
	None	5 (2.60)	14 (14.29)	2 (1.40)	14 (10.70)
	Others	4 (2.10)	3 (3.06)	9 (6.30)	1 (0.80)
Transportation subsidy (Multiple choice)	None	80 (41.20)	53 (54.08)	36 (25.40)	49 (37.40)
	Public transport subsidy	24 (12.40)	7 (7.14)	39 (27.5)	11 (8.40)
	Private car subsidy	11 (5.70)	3 (3.06)	9 (6.30)	1 (0.80)
	NS tickets with discount	27 (13.90)	16 (16.33)	33 (23.20)	18 (13.70)
	Student discount	60 (30.90)	20 (20.41)	44 (31)	57 (43.50)
	Others	7 (3.60)	1 (1.02)	4 (2.80)	0 (0)
Driving license	Yes	134 (69.10)	47 (47.96)	108 (76.10)	81 (61.80)
	No	59 (30.40)	50 (51.02)	33 (23.20)	49 (37.40)
	Prefer not to say	1 (0.50)	1 (1.02)	1 (0.70)	1 (0.80)
Employment status	Student	120 (61.90)	69 (70.41)	80 (56.30)	112 (85.50)
	Full-time employed	54 (27.80)	22 (22.45)	47 (33.10)	15 (11.50)
	Part-time employed	10 (5.20)	5 (5.10)	10 (7)	2 (1.50)
	Self-employed	3 (1.50)	1 (1.02)	2 (1.40)	0 (0)
	Seeking for a job	2 (1)	0 (0)	3 (2.10)	2 (1.50)
	Retired	2 (1)	0 (0)	0 (0)	0 (0)
	Other	3 (1.50)	1 (1.02)	0 (0)	0 (0)

5.2 Motivations for using bike-sharing

It is crucial to explore motivations for using bike-sharing, both to improve the attractiveness of bike-sharing systems and help to design the future bike-sharing systems (Fishman, 2016). Respondents who had used bike-sharing systems were asked to identify their main motivations from a defined set of options, as shown in Figure 1. “No fixed pick-up and drop-off locations” (59.18%) has been found to be most important motivator for Mobike users. This observation is consistent with an earlier study of Li et al. (2018), who focused on dockless bike-sharing usage pattern and influencing factors. 52.04% of Mobike user noted “Convenience of the app and payment method” as one of the most important motivations, followed by “Less effort than walking” (42.86%). For OV-fiets users, “Saving time” (59.20%）has emerged as the most predominant motivation. This result is consistent with the previous research (Jäppinen et al., 2013), which emphasized the importance of time competitiveness as a motivation for bike-sharing. “Less effort than walking” （55.60%）was identified as the second strongest motivation, with “Good quality of bicycles” (44.40%) recognized as the third strongest motivation. Swapfiets users noted “Less worried about being stolen/damaged” (55.70%), “Good quality of bicycles” (52.70%) and “Less effort than walking” (38.20%) as the top three motivations. One of the advantages of Swapfiets is that the lease company will fix the broken bicycles instead of done by the users. Interestingly, “Trendy travel mode” was not a popular option by Mobike users (3.06%), OV-fiets users (1.40%) and Swapfiets users (8.40%). In addition, more Swapfiets users (52.70%) and OV-fiets users (44.40%) reported that they thought the quality of the bicycles were good, whereas only 6.12% of Mobike users reported that.

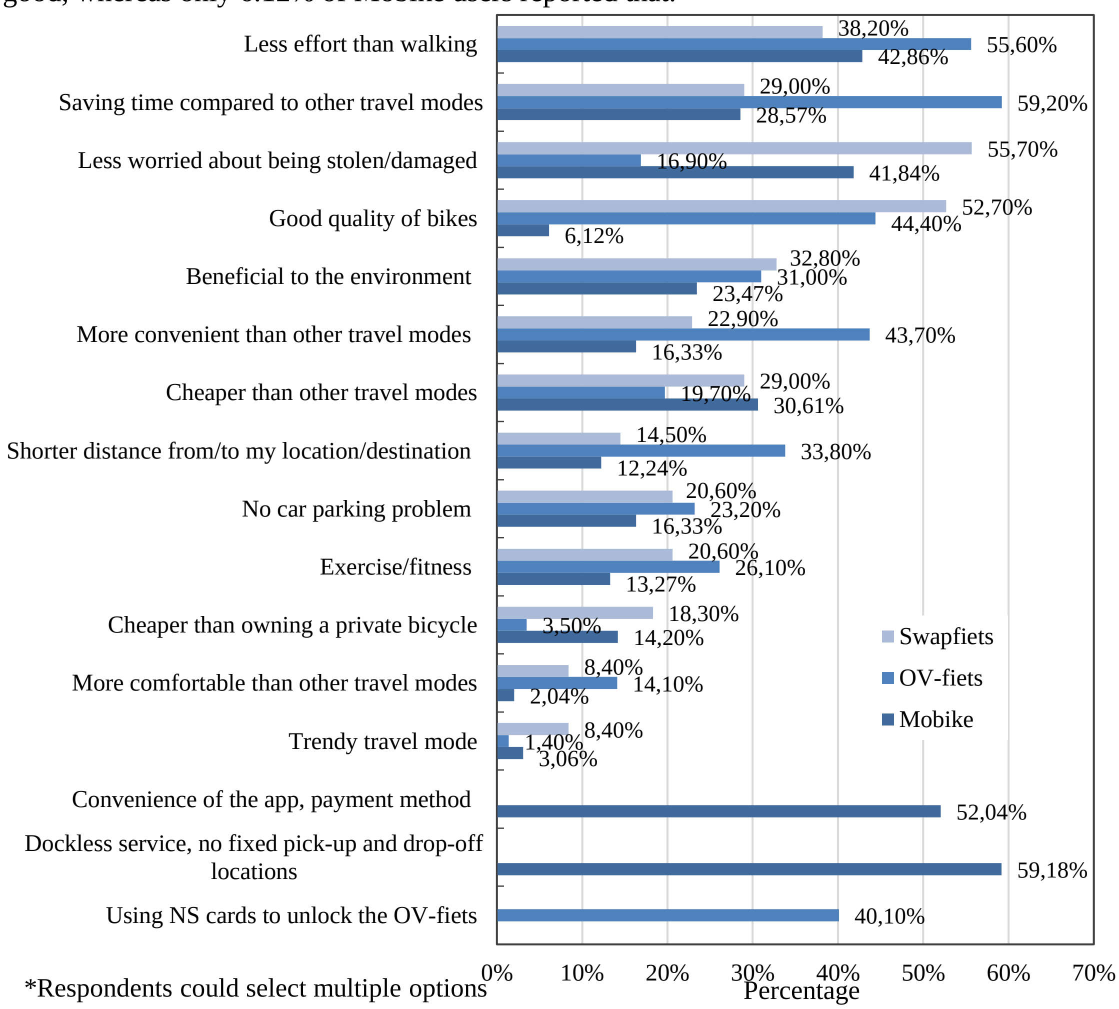

Figure 1 Motivations to become a bike-sharing user. (The percentage of a certain option is calculated by the related number of selections divided by the total number of respondents)

5.3 Modal shift patterns

We measured the modal shift dynamics caused by bike-sharing systems for the following travel modes: walking, private bicycle, Swapfiets, OV-fiets, Mobike, private e-bike, bus/tram, train, private car (driver/passenger), taxi and carsharing. Given the distribution of the answers, we grouped the answers “much more often”, “more often” into the category “Increase”, and “less often” “much less often” into the category “Decrease”. Figure 2 displays the differences in overall modal shift caused by three different bike-sharing systems.

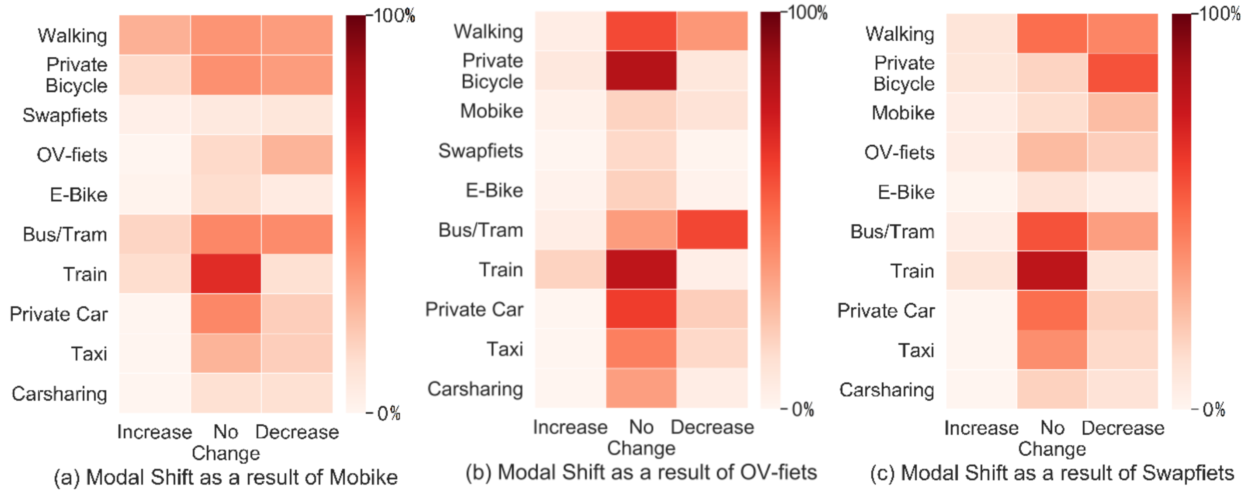

Figure 2 Modal Shift as a result of different bike-sharing systems

The sample exhibited the decrease in walking as a result of Swapfiets (by 41.75%), OV-fiets (by 36.13%) and Mobike (by 34.57%). Contrary to the finding of Martin and Shaheen (2014), who established that there was an increase in private bicycle use as a result of bike-sharing in both Minneapolis and Washington DC, more bike-sharing users in Delft shifted away from private bicycle than towards it. Specifically, 56.31% of Swapfiets users and 34.57% of Mobike users reported that they have reduced their private bicycle usage, while only 8.40% for OV-fiets users. This result indicates that Swapfiets and Mobike are more prominent modes in the replacement of their own bicycles. A marginal change in e-bike usage was reported by all the bike-sharing users. Train use increasing was reported by OV-fiets users (16.81%), Mobike users (13.58%) and Swapfiets users (9.71%) as they can park the shared bicycles in or near the train stations when accessing/egressing the train. The reason why OV-fiets users outperformed the other two systems is that OV-fiets was design by its nature to facilitate fist/last mile train trips. Meanwhile, more Mobike users (16.05%) reported that they used train less than Swapfiets users (9.71%) and OV-fiets users (4.20%), as Mobike works better to replace train for one-way trip because of the advantage of no fixed docking station. More bike-sharing users shifted away from bus/tram than toward them, which aligned with the result of Shaheen et al. (2013). Particularly, 59.66% of OV-fiets users reported they used bus/tram less than before, which was much larger than Mobike users (39.51%) and Swapfiets users (33.98%). In addition, compared to Swapfiets users (4.85%) and OV-fiets users (5.04%), more Mobike users (16.05%) reported that they used bus/tram more than before. The reason may be explained by the fact that Mobike users would access and egress bus/tram more conveniently as they have no concern about bicycle parking around bus/tram stations. Reductions on private car/passenger and taxi were similar for Mobike (37.04%), OV-fiets (33.61%) and Swapfiets (32.04%). As to the modal shift patterns within bike-sharing systems, 27.16% of Mobike users reported they used OVfiets less than before. Besides, obvious decline in Mobike use (24.27%) and OVfiets use (18.45%) were reported by Swapfiet users, which is in line with the finding of Boor (2019), which concluded that Swapfiets was one of the most direct competitors with the docked and dockless bike-sharing systems in Delft.

5.4 Modal shift regarding commuting

The modal shift dynamics in commuting after the introduction of bike-sharing systems is presented in Sankey diagrams in Figure 3 to Figure 5. Commuting in the context of this study is defined as the main daily travel activities, including government/office work and personal commercial business and school, as Nkurunziza et al. (2012) defined. For each of the bike-sharing systems, a Sankey diagram is constructed. These show the pre transport mode for commuting on the left and the post modes on the right of the graph. The thickness of each line represents the percentage of modal shift, with colors to distinguish different types of travel modes. Travelers can use either single mode or multiple modes for commuting. For Mobike users (Figure. 3), 28.91% of the total amount shifted away directly from private bicycle (20.48%), walk (7.23%) and Swapfiets (1.20%). Whereas, 18.07% and 6.02% of the total travelers still used private bicycle and walk for commuting. Additionally, 24.10% of Mobike users indicated that they replaced walking (8.43%) and private bicycle (7.23%) by Mobikes in their multimodal commuting trips. However, 19.28% of the Mobike users remained their original commuting multimodal modes.

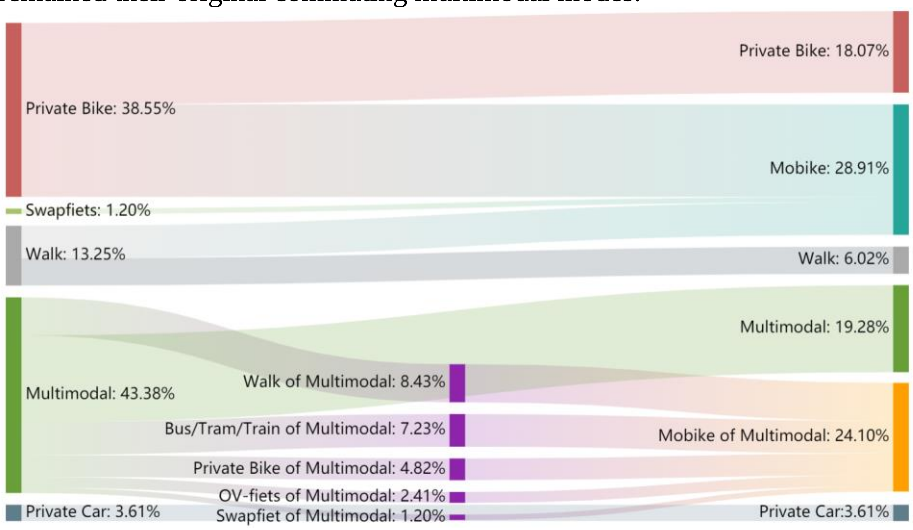

Figure 3 Modal shift for commuting of Mobike users

For OV-fiets users (Figue. 4), they mainly used walking and multimodal travel for commuting before they used OV-fiets. One of the interesting findings was observed that all the 34.26% of OV-fiets users still chose to ride by private bikes to commute. So, no mode shift is observed for commuting by private bikes in this user group. 41.67% of OV-fiets users who used multimodal for commuting did not change their modes, while 16.67% of this user group replaced bus/tram/train legs by OV-fiets, followed by walk (3.70%) and private bicycle (2.78%).

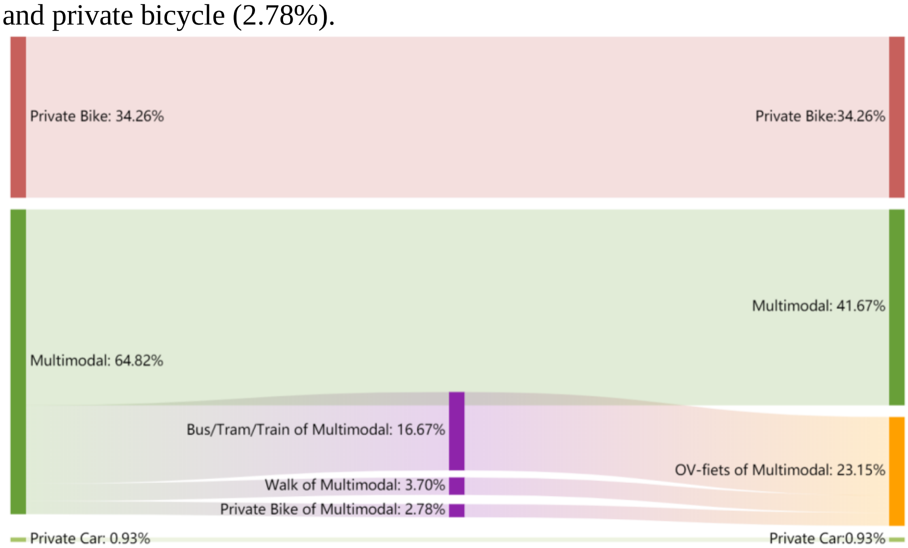

Figure 4 Modal shift for commuting of OVfiets users

As shown in Figure. 5, most Swapfiets users shifted from private bicycle (30.48%) and walk (8.58%) to Swapfiets for commuting. This trend is followed by Mobike (3.81%) and OV-fiets (0.95%), which are relatively low. 42.85% of Swapfiets users shifted from a certain mode (including walking, private bike, bus/tram/train) to Swapfiets in multimodal trips. Specifically, walk and private bicycle share the same percentage of 16.19%, followed by bus/tram/train (10.48%).

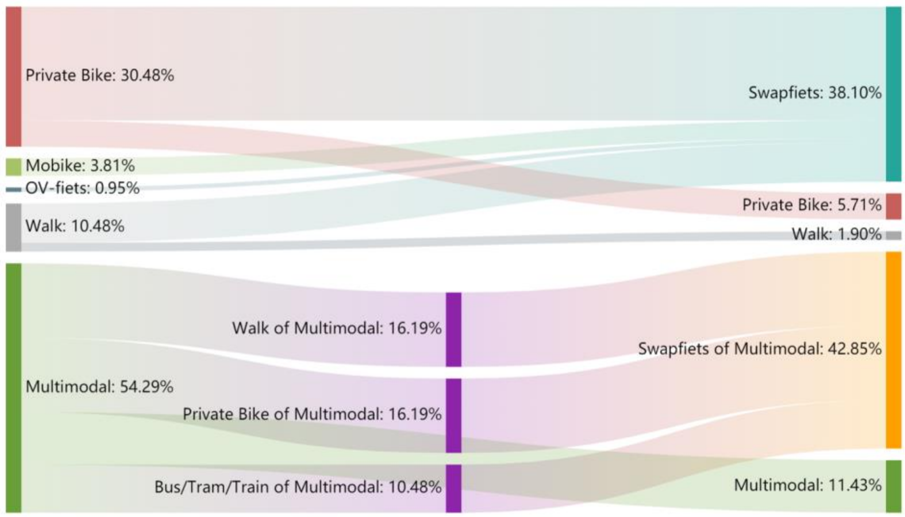

Figure 5 Modal shift for commuting of Swapfiets users

In sum, (1) Swapfiets has resulted in the most obvious modal shift (80.95%=38.10%+42.85%), followed by Mobike (53.01% = 28.91%+24.10%) and of OVfiets (23.15%); (2) For the single mode Mobike and Swapfiets commuters, walk and private bicycle were replaced most. (3) For the multimodal Mobike commuters, they replaced public transport modes more than multimodal Swapfiets commuters relatively. This can be explained: the Mobike could be found near the public transport stations and Mobike users could integrate Mobike with public transport, whereas Swapfiets users would encounter with parking problems when accessing the public transport and they have to pick up Swapfiets bicycles when egressing the public transport; (4) For the multimodal OV-fiets commuters, they prefer to replace public transport, which is reasonable as they can borrow OV-fiets in or near public transport stations for commuting; (5) Regarding single mode trips, Mobike and Swapfiets commuters replaced walk and private bicycle for commuting, but this was not observed in OV-fiets commuters. The reason may be explained by the fact that OV-fiets has to be returned to stations within 24 hours to avoid extra cost, which reduces its flexibility and applicability for serving as a single commuting mode compared with Mobike and Swapfiets.

5.5 Binary logit model results

Only the samples with all the needed information over three independent variables are included in the model. A correlation coefficient test is performed to check the co-linearity among the variables. The test confirms that no co-linearity exists among these variables. Three binary logit models were estimated, with “No shift” as reference categories (See Table 2). Models were stepwise adjusted by firstly including the socioeconomic variables, secondly adding commuting trip variables, and thirdly including motivation variables. Only the variables with acceptable statistical significance ($p < 0.10$) were kept in subsequent model runs (Riggs, 2015). These selections were reported in a final model. The final models are depicted in Table 4, only including the variables that are significant at the 90% interval. The R^2 values of the three models are equal to 0.314, 0.345 and 0.337, respectively, which fall in the acceptable range of 0.2–0.4 (Fan et al., 2019; Talat, 2013).

As illustrated in Table 4, the selected factors of significancy may have different effects on modal shift in commuting. For example, “No stolen/demaged problem” and “Cheaper than other modes” are significant factors affecting Mobike and Swapfiets users to shift their travel modes, but not for OV-fiets users. As Ji et al. (2016) indicated that commuters who had experienced bicycle theft were more likely to use bike-sharing service. Mobike users do not need to concern bicycle theft problem. Similarly, if Swapfiets gets stolen, users can get new bicycles within 12 hours and only pay € 40 deductible cost, which is much cheaper than buying a new bicycle. Commuters who consider Mobike and Swapfiets as economical modes are more likely to use them for commuting purposes. This is reasonable because more than 85% of Swapfiets users and 70% of Mobike users are students with relatively low income (see Table 3).

TABLE 4 The Results of Model Estimation

	Mobike		**OV-fiets**		**Swapfiets**	
Variables	**Coef.**	**P>z**	**Coef.**	**P>z**	**Coef.**	**P>z**
Socioeconomic variables						
Male (gender)	1.597	0.030**	—	—	—	—
Public transport subsidy	—	—	1.230	0.058*	—	—
Student discount	—	—	—	—	-2.234	0.024**
Private bicycle ownership	—	—	-2.723	0.000***	—	—
Commuting trip variables						
Commuting distance	—	—	4.690	0.009**	—	—
Travel with multiple modes	0.069	0.003***	—	—	—	—
Motivation variables						
No stolen/damaged problem	1.610	0.018**	—	—	1.636	0.035**
Cheaper than other modes	1.520	0.027**	—	—	2.251	0.013**
Good quality of bicycles			2.230	0.006**	1.516	0.038**
Convenient	—	—	0.789	0.098*	—	—
Short Trip	—	—	-1.379	0.047**	—	—
	N =80		N =113		N =99	
	Pseudo R^2=0.314		Pseudo R^2=0.345		Pseudo R^2=0.337	

Note: * Statistically significant at the 10% level (i.e., $p<0.10$);
** Statistically significant at the 5% level (i.e., $p<0.05$);
*** Statistically significant at the 1% level (i.e., $p<0.01$).

"Good quality of bicycles" is a significant factor affecting OV-fiets and Swapfiets users to shift, but not for Mobike users. This result coincides with the results from Figure 2, in which 52.70% of Swapfiets users and 44.40% of OV-fiets users reported that they thought the quality of the bicycles were good, while only 6.12% of Mobike users agreed with this statement. "Public transport subsidy" encourages multimodal commuters to shift to OV-fiets, which is reasonable because OV-fiets was launched to promote first/last mile integration with public transport (Boor, 2019). However, Swapfiets users who are beneficial from "Student discount" are less likely to commute by Swapfiets as they have more economical travel modes to choose, such as bus and tram (free of charge).

Some factors only affect the modal shift of a certain group of bike-sharing users in commuting. "Male" commuters are more likely to use Mobike, which is consistent with the gender differences of dockless bike-sharing usage reported by Zhou and Ni. (2018). Commuters are more likely to use Mobike when they travel with "Multiple modes". This finding supports previous studies which showed that single modal travelers were more likely to be stable commuters whereas people with multimodal travel behavior were more willing to consider and use new transport options such as dockless bike-sharing (Heinen, 2018; Joost et al., 2018). OV-fiets users are less likely to shift to OV-fiets if the trips are "Short" or more suitable for taking "Private bicycle". This finding is similar with the result of Ji et al. (2016), which concluded that travelers were more inclined to use private bicycles for short accessing/egressing trips instead of docked bike-sharing. Additionally, a longer "commuting distance" appears to result in increasing usage of OV-fiets for commuting. This may be explained by that travelers are reluctant to choose slower modes like walking so as to save time. Finally, as OV-fiets achieves a good connection with public transport, commuters may consider it as a "Convenient" mode and shift to this mode.

6 Conclusions and recommendations

Bike-sharing has experienced a rapid growth around the world, providing new options for transport as a main mode of travel and/or supportive to public transport. It encourages people to make the modal shift from other sustainable transport (i.e., bus, tram, train, walking) and motorized transport (i.e., car, taxi and carsharing). This paper firstly compares the socio-demographic characteristics between bike-sharing users and non-bike-sharing users. Next, the motivations for joining bike-sharing schemes were identified. Finally, travelers' modal shift behavior and the influencing factors were investigated by establishing binary logit models.

For comparative purposes, the sample size was divided into non-bike-sharing users and bike-sharing users (including Mobike, Swapfiets and OV-fiets users). In terms of age, gender, monthly (gross) income, education and employment status, the sample exhibited consistency between non-bike-sharing users and bike-sharing users. However, other socio-demographic characteristics varied between non-bike-sharing users and bike-sharing users. Particularly, Mobike users are more likely to be non-Dutch and have no driving license, whereas the situation with the other three kinds of respondents is on the opposite. As for vehicle ownership, OV-fiets group has the highest proportion of private bicycle(s) (97.90%) and non-bike-sharing users have the highest proportion of car ownership (26.30%). Another obvious difference existed in transportation subsidy. Specifically, most OV-fiets users (74.60%) have transportation allowance and 54.08% of Mobike users have no transportation allowance. In addition, Swapfiets users have a much higher proportion in terms of student discount from government (43.50%). The descriptive results have clearly demonstrated the chacteristics of each user group.

Interestingly, "Less effort than walking" was identified as one of the top three motivations by three kinds of bike-sharing members, indicating that bike-sharing is popular to replace walking. Other key motivations included "No fixed pick-up and drop-off locations" and "Convenience of the app and payment method" for Mobike members, "Saving time" and "Good quality of bicycles" for OV-fiets members, and "Less worried about being stolen/damaged" and "Good quality of bicycles" for Swapfiets users. Those motivations were closely related to the characteristics of different bike-sharing systems.

Modal shift patterns were explored from two perspectives: travel modes and commuting purpose. Martin and Shaheen (2014) pointed that modal shift patterns caused by bike-sharing varied from city to city. Different from the contexts of Washington DC and Minneapolis where an increased private bicycle usage had been found, bike-sharing users reduced their private bicycle usage in Delft. Bike-sharing users reduced the use of walking, private bicycle, bus/tram and car. Particularly, the train use increased after the introduction of bike-sharing systems. In addition, observed shifts within bike-sharing systems indicated that the competitive relationship was existent among bike-sharing systems. Furthermore, Sankey diagrams were used to examine the modal shifts regarding commuting by separating single and multiple modes. Swapfiets showed a most significant influence on both single mode and multimodal trips, whereas the OV-fiets had the least influence. Mobike and Swapfiets were popular in replacing single mode trips than OV-fiets. The most obvious shifts in multimodal trips were walking for Mobike, bus/tram/train for OV-fiets, and walking and private bicycle for Swapfiets.

The regression study reveals newly important insights into the factors associated with modal shift in commuting. The analysis identifies that the effects of various socioeconomic, commuting trip and motivation factors on modal shift varies among different bike-sharing systems. Factors including "Being male", "No stolen/damaged problem", "Cheaper than other modes" and "Travel with multiple modes" have positive impact on Mobike commuters. Regarding the impact on Swapfiets commuters, "No stolen/damaged problem", "Cheaper than other modes" and "Good quality of bicycles" have positive impact, whereas "Student discount" has negative impact. Commuters who have bicycles are less likely to use OV-fiets. On the contrary, “Public transport subsidy”, “Long commuting distance”, “Good quality of bicycles” and “Convenient” encourage commuters to use OV-fiets.

According to the results, several practical implications for encouraging commuters to use bike-sharing systems are given as follows.

(1) “Good quality of bicycles” is seen as a modal shift motivation for OV-fiets and Swapfiets commuters, but not for Mobike. This indicates that the quality of Mobike bicycles should be improved. Meanwhile, the operating mechanism for bike maintenance needs to be strengthened, as Ma et al. (2019) have concluded that encountering bike malfunctions will reduce user satisfaction and loyalty to Mobike.

(2) A gender disparity in Mobike commuters is revealed. Females are less likely to use Mobike for commuting. The unpopularity in female commuters toward Mobike may be due to heavy bicycle weight. To design a lighter bicycle may help to reduce the gender gap in Mobike commuting use.

(3) Although this study reveals that multimodal commuters incline to use Mobike for integration with other modes, the current parking policy in the study area is unfriendly to Mobike. Both OV-fiets and Swapfites bicycles are allowed to park in the underground parking facility close to the trains while Mobike has to be parked 150m walking away from train stations. Mobike should get equal market position (e.g., comparable parking facilities at train stations) so that Mobike can provide users a better integration service with public transit modes.

(4) Commuters who consider Swapfiets and Mobike as cheaper modes than others are more likely to use them. However, this situation was not perceived by the OV-fiets group. Compared to Mobike and Swapfiets, the cost for using OV-fiets (€ 3.85 per 24 hours) may be a bit more expensive. It is suggested that a more flexible time-based pricing system could be proposed to OV-fiets for attracting one-way commuter who does not want to rent the OV-fiets for the entire day.

(5) Similar with the docked bike-sharing syetems in Hangzhou and Nanjing, China, where personal public transport smartcard can be used interchangeably between bike-sharing systems and public transit networks, OV-fiets can be accissible by the same type of smartcards in the Netherlands. In Hangzhou, bike-sharing users can get an extra 30 min free usage time with a transfer to bus (Yang et al., 2016). In Nanjing, a policy was introduced that travelers with a transfer between a bus, subway, tram or ferry can be rewarded by US$0.16 (1 RMB) if such a personal smartcard was used (Ma et al., 2018). These policies can also be introduced to promote OV-fites.

The study can be further improved by getting a bigger sample size. Broader insights could possibly be obtained if the “Shift to bike-sharing” option can be decomposed into the specific travel modes, so that we can more accurately explore the modal shift factors by establishing nested logit models. Additionally, future work will be necessary to explore the factors influence the modal shift within bike-sharing systems, as well as the influential factors on modal shift from non-bike-sharing modes to bike-sharing

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Author contribution statement:

The authors confirm contribution to the paper as follows: study conception and design: Xinwei Ma, Yufei Yuan and Niels van Oort; data colletion: Xinwei Ma, Yufei Yuan and Niels van Oort; analysis and interpretation of results: Xinwei Ma; comment to draft manuscript: Serge Hoogendoorn, Yufei Yuan and Niels van Oort.

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